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Suplementary Information:

Diagenetic Study Based on Petrography: Implications for Sandstone Porosity of the Peunasu Formation, Pulau Nasi, Aceh

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Method

This study employs petrographic methods to observe the components and texture of sandstone. There are two methods for petrographic observation using a polarizing microscope: plane-polarized light (PPL) and cross-polarized light (XPL) (see Figure S1). These two observation techniques complement each other in identifying rock constituents. Using XPL observation, minerals that compose rocks—such as quartz, lithic fragments, and matrix—can be clearly distinguished (refer to Figure S1). In addition, during PPL observation, oxide cement is easily recognizable due to its blackish-brown color (see Figure S1).

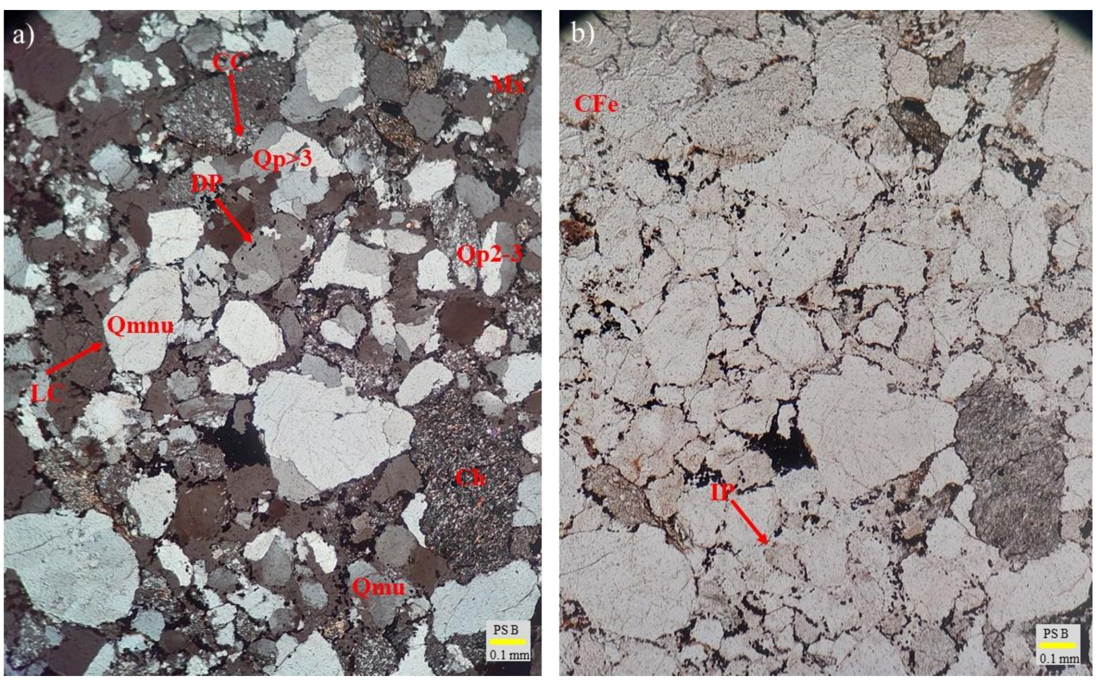


Figure S1. Two methods of microscopic observation: (a) cross-polarized light (XPL), (b) plane-polarized light (PPL). Grains will be more easily observed in XPL, while oxide cement is easily observed in PPL.

The petrographic analysis involves examining the texture of sedimentary rocks, including aspects such as grain size, sorting, roundness, grain contact, and porosity. When using a polarizing microscope, a scale is available to measure the size of mineral grains. Determining grain size is essential for classifying sedimentary rocks, as it can be referenced using the Wentworth scale [19] (Figure S2).

	US Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL		4096		-12	
		1024		-10	Boulder
		256	256	-8	
		64	64	-6	Cobble
		16		-4	Pebble
	5	4	4	-2	
	6	3.36		-1.75	
	7	2.83		-1.5	Granule
	8	2.38		-1.25	
	10	2.00	2	-1.0	
SAND	12	1.68		-0.75	
	14	1.41		-0.5	Very coarse sand
	16	1.19		-0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	Coarse sand
	30	0.59		0.75	
	35	0.50	½	1.0	
	40	0.42		1.25	
	45	0.35		1.5	Medium sand
	50	0.30		1.75	
	60	0.25	¼	2.0	
	70	0.210		2.25	
	80	0.177		2.5	Fine sand
	100	0.149		2.75	
	120	0.125	⅛	3.0	
	140	0.105		3.25	
	170	0.088		3.5	Very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
MUD – SILT	270	0.053		4.25	
	325	0.044		4.5	Coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	Medium silt
		0.0078	1/128	7.0	Fine silt
		0.0039	1/256	8.0	Very fine silt
MUD – CLAY		0.0020		9.0	
		0.00098		10.0	Clay
		0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

Figure S2. Wentworth scale [19]

Furthermore, we observe the sorting texture, which denotes the variation in grain size found within sedimentary rocks. A relatively uniform grain size indicates a very well sorting, whereas considerable non-uniformity in grain size is indicative of poor sorting [20], [21]. A textural comparison chart that delineates various degrees of sorting is provided in Figure S3.

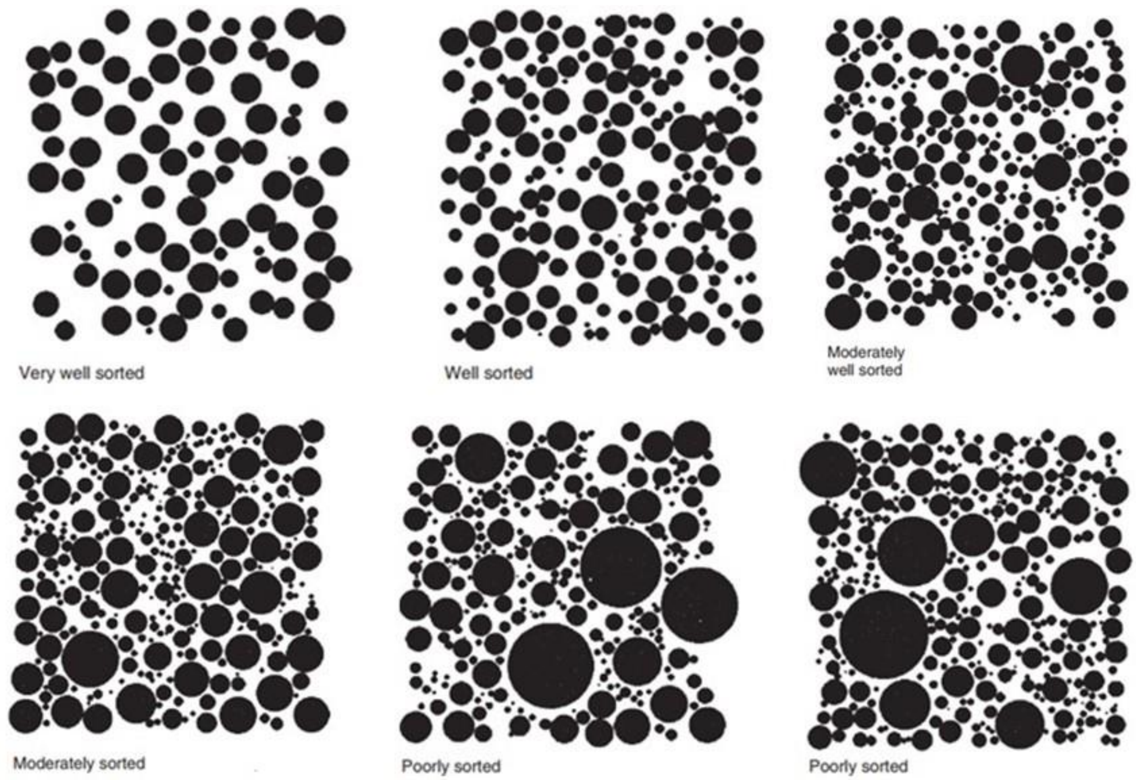


Figure S3. A textural comparison chart of sorting [20], [21]

Roundness texture is determined by the degree of mineral roundness. A mineral is described as having a well-rounded texture if it is more rounded. On the other hand, if the mineral has an angular shape, it is referred to as having a very angular texture [22]. Images of grains used to estimate the roundness of sedimentary grains can be found in Figure S4. Additionally, grain contact texture is assessed by observing the interaction between grains [23]. A diagram illustrating these grain contacts is also included in Figure S5.

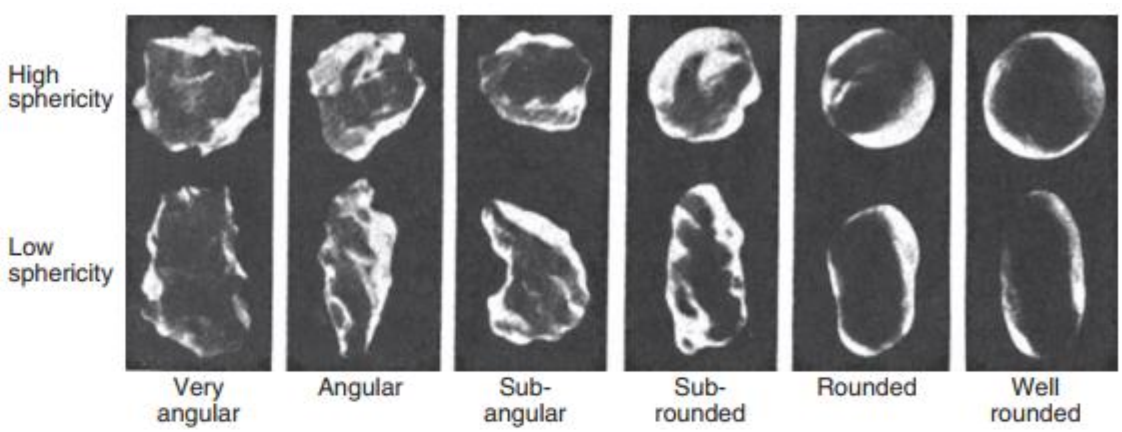


Figure S4. A textural comparison chart of roundness

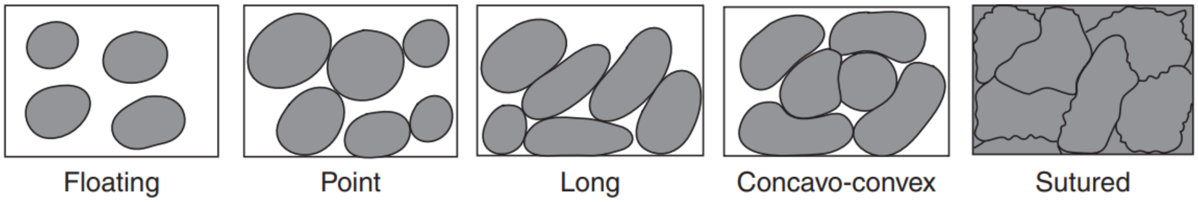


Figure S5. Illustrating diagram of grain contacts

The last texture analyzed is porosity. It is identified using a mica comparator under a microscope. In XPL observation, it is characterized by a consistent color that does not change when the sample table is rotated. The difference between grains and porosity can be seen in Figure S6.

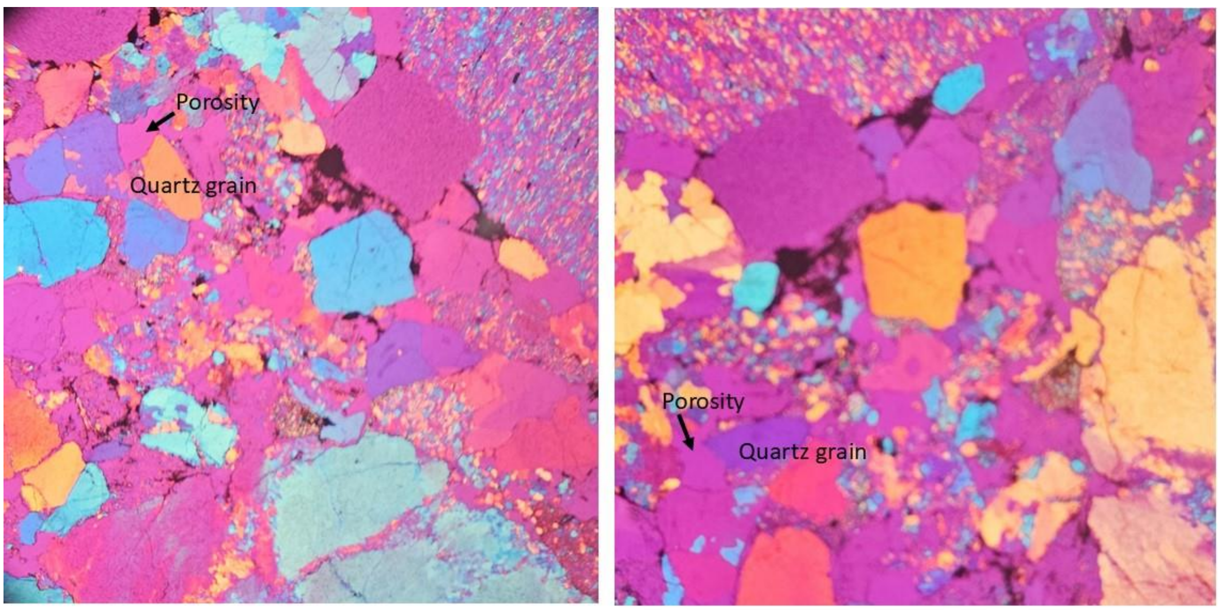


Figure S6. The distinction between porosity and grains can be observed using a mica comparator. In the initial observation (**Left)**, porosity appears purple while the quartz grain is yellow. After rotating the sample position **(Right)**, porosity retains its color, but the quartz grain shows a color change.

The next phase of the research focuses on capturing photographic images of thin section samples to quantify the proportions of clastic grains, matrix, cement, and porosity. This quantitative analysis utilizes the point-counting technique and apply the *Jmicrovision software*. This software randomly creates points on each mineral. The number of points is reported as a percentage of the total. In this study, we scored 1,500 points covering all the sample's minerals.

Figure S7 provides an example of the results from our point counting. In this figure, each monocrystalline quartz mineral (Qm) is marked with red point. Similarly, other minerals are marked with specific colors. The Jmicrovision software automatically calculates the percentage of points assigned to each mineral. As a result, we obtain the percentages for quartz, lithic minerals, muscovite, matrix, cement, and porosity, which is attached in Table S1.

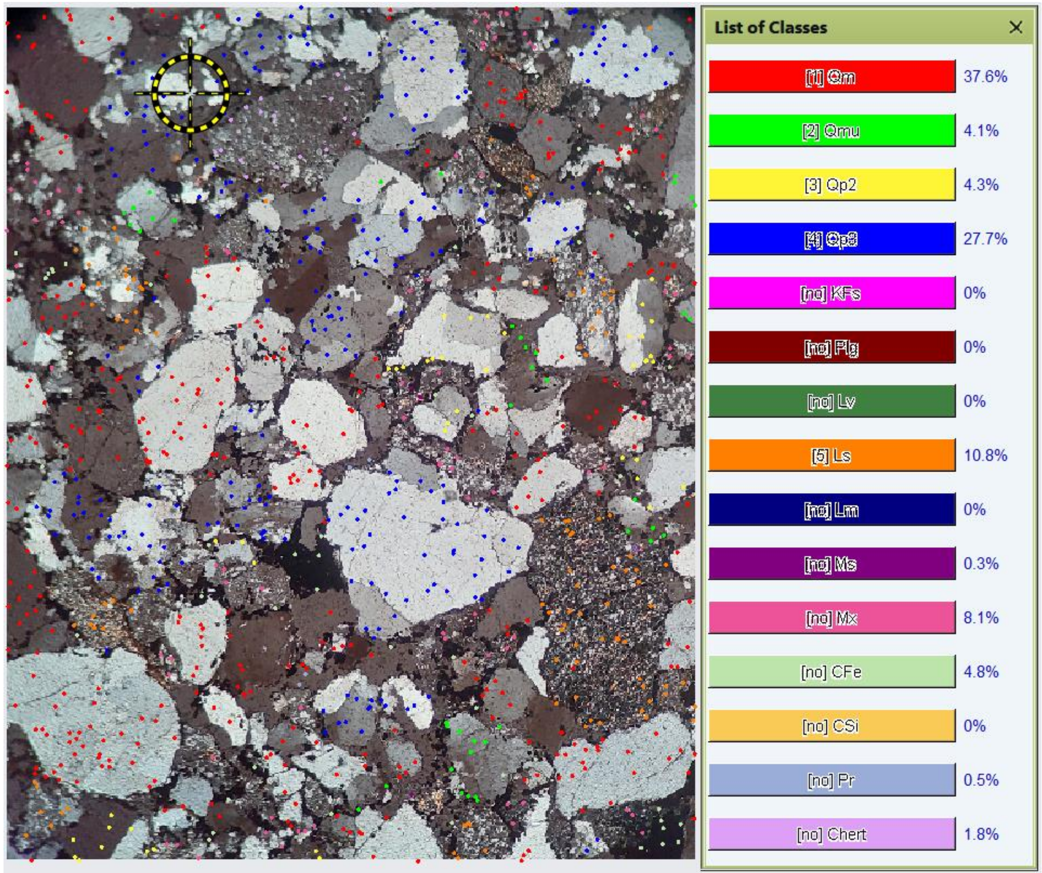


Figure S7. An example of the results of point counting.

The next phase of the research involves describing the rock type. According to the Wentworth scale [19], this sedimentary rock is classified as sandstone. We will use the QFL diagram [25] to determine the specific classification of the sandstone. This diagram includes the components of quartz, feldspar, and lithic fragments, which together should total 100%. Since the total percentage of these three components does not equal 100%, we normalize the percentages of quartz, feldspar, and lithic fragments. The results of our normalization are provided in Table S2.

Figure S8 presents a QFL diagram, which categorizes three sections based on the percentage of the matrix present in the rock. The diagram's usage accounts for the matrix in the rock. If the matrix ranges from 0% to 15%, the arenite section of the diagram is utilized. The Wacke section is applicable for a matrix between 15% and 75%. If the matrix exceeds 75%, the mudrock section should be applied. For example, sample PS B has a matrix of 8.1%, so we refer to the arenite section of the diagram. By plotting the normalized values of quartz, feldspar, and lithic fragments, we identify the sandstone type as sublitharenite. This process is similar to that of the other samples.

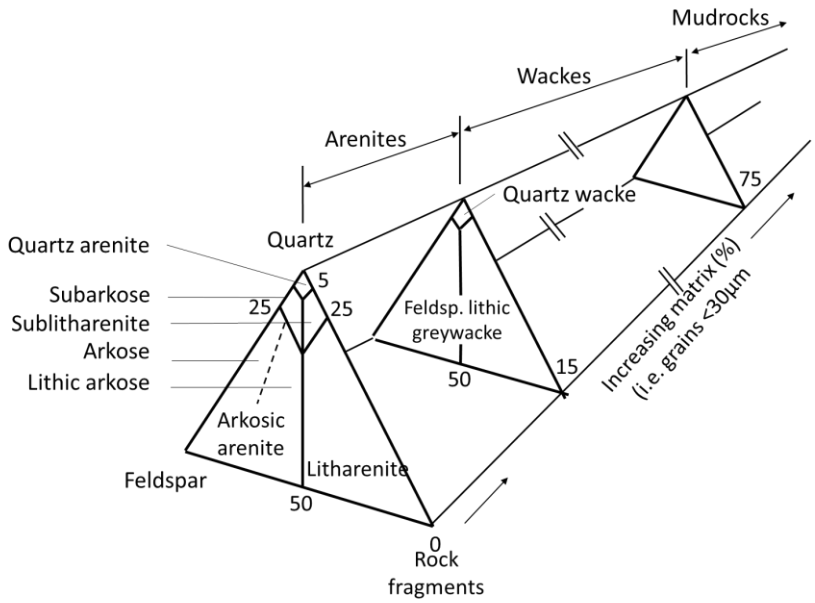


Figure S8. QFL diagram for sandstone classification

Results

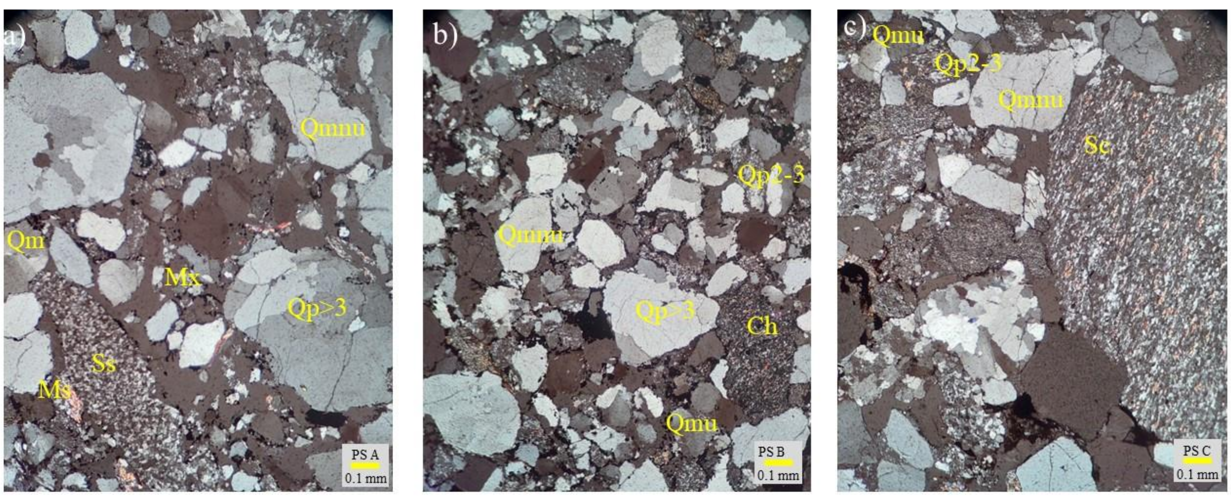
Table S1. Description of composition and texture of the Peunasu Formation sandstone

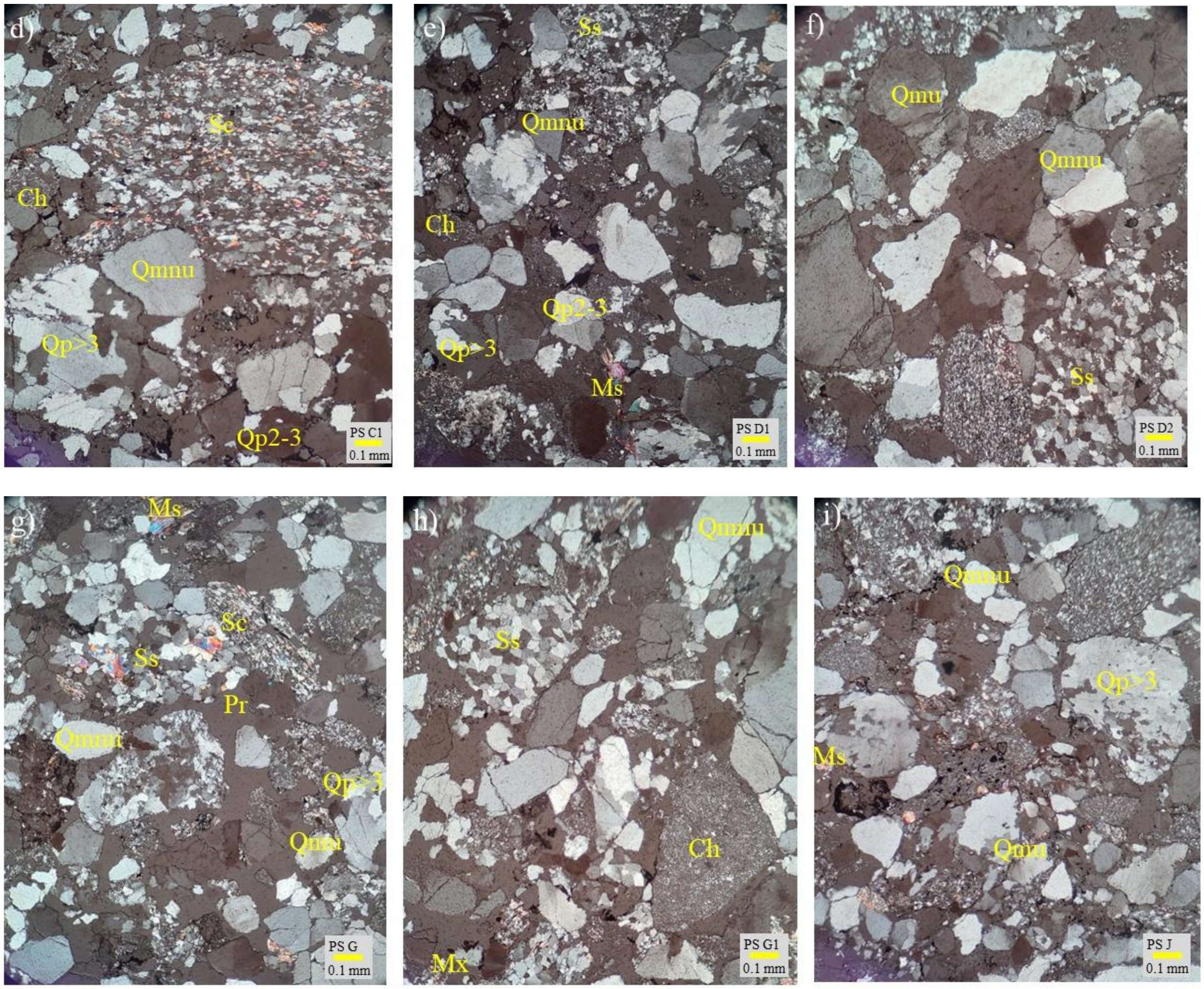
Description		PS A	PS B	PS C	PS C1	PS D1	PS D2	PS G	PS G1	PS J
Texture	Grain size range (mm)	0.1 – 1.0	0.1 – 0.6	0.1 – 1.5	0.1 – 1.0	0.1 – 0.5	0.1 – 0.7	0.1 – 0.7	0.1 – 0.6	0.1 – 0.6
	Grain size average (mm)	0.5	0.25	0.5	0.25	0.2	0.3	0.2	0.3	0.2
	Sorting	Poor	Moderate	Poor	Poor	Moderate	Moderate	Moderate	Moderate	Moderate
	Roundness	Subrounded - rounded	Subrounded - rounded	Subrounded - rounded	Subrounded - rounded	Subrounded – rounded	Subrounded - rounded	Subrounded – rounded	Subrounded – rounded	Subrounded – rounded
	Grain contacts	Long to concave convex	Long to concave convex	Long to concave convex	Long to concave convex	Long to concave convex	Long to concave convex	Point to long	Point to concave convex	Point to long
Composition (%)	Qmnu	27.1	37.6	26.4	20.6	32.1	33.7	24.6	31.8	30.4
	Qmu	6.8	4.1	2	1.2	5.6	9.1	2.9	5.7	3.6
	KFs	-	-	-	-	-	-	-	-	-
	Plg	-	-	-	-	-	-	-	-	-
	Qp 2-3	0.7	4.3	1.6	8.7	4.2	5.9	2.2	3.5	1.2
	Qp>3	27.3	27.7	4.3	18.2	15.2	7.6	14.2	9.2	15.2
	Ls	10	10.8	8.6	-	14	23.2	22	12.8	16.4
	Lv	-	-	-	-	-	-	-	-	-
	Lp	-	-	-	-	-	-	-	-	-
	Lm	-	-	30.6	36.5	-	-	5	-	-
	Ch	-	1.8	-	0.7	2.7	-	-	9.7	2
	CFe	4.3	4.8	3.1	3.8	4.6	0.2	5.8	0.8	3.5
	Csi	-	-	-	0.9	0.1	0.9	0.6	-	-
	Mx	12.3	8.1	19.3	5.2	11.8	16.5	4.7	16.6	20.4
	Pr/Vn/Fr	8.6	0.5	3.4	3.8	7.5	2.9	16.8	8.3	6.8
	Ms	2.9	0.3	0.7	0.4	2.2	-	1.2	1.6	0.5
	Total	100	100	100	100	100	100	100	100	100
	Rock name [25]	Sublitharenite	Sublitharenite	Lithic greywacke	Litharenite	Litharenite	Lithic greywacke	Litharenite	Lithic greywacke	Lithic greywacke

Table S2. Normalized result of quartz (Q), feldspar (F), and rock fragment (L) percentage.

Sampel	**Q**	**F**	**L**	**Total**	**Rock name** [25]
PS A	77.2	0.0	22.8	100	Sublitharenite
PS B	79.4	0.0	20.6	100	Sublitharenite
PS C	42.0	0.0	58.0	100	Lithic greywacke
PS C1	37.4	0.0	62.6	100	Litharenite
PS D1	72.9	0.0	27.1	100	Litharenite
PS D2	64.8	0.0	35.2	100	Lithic greywacke
PS G	50.5	0.0	49.5	100	Litharenite
PS G1	74.6	0.0	25.4	100	Lithic greywacke
PS J	67.5	0.0	32.5	100	Lithic greywacke

Figure S9. Thin-section photograph a) PS A, b) PS B, c) PS C, d) PS C1, e) PS D1, f) PS D2, g) PS G, h) PS G1, i) PS J. (Qmu = Undulating monocrystalline quartz; Qmnu = Non-undulating monocrystalline quartz; Qp2-3 = Polycrystalline quartz with 2 – 3 unit per grain; Qp>3 = Polycrystalline quartz with more than 3 unit per grain; Sc = Schist; SS = Sandstone; Ch = Chert; Ms = Muscovite; Mx = Matrix; Csi = Silica cement; CFe = Iron oxide cement; Pr = Porosity)




d)
Sc
Ch
Qmnu
Qp>3
Qp2-3
PS C1
0.1 mm
e)
Ss
Qmnu
Ch
Qp2-3
Qp>3
Ms
PS D1
0.1 mm
f)
Qmu
Qmnu
Ss
PS D2
0.1 mm
g)
Ms
Sc
Ss
Pr
Qmnu
Qp>3
Qmu
PS G
0.1 mm
h)
Qmnu
Ss
Ch
Mx
PS G1
0.1 mm
i)
Qmnu
Qp>3
Ms
Qmu
PS J
0.1 mm